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RESEARCH MEMORANDUM

SOME MEASUREMENTS OF LANDING CONTACT CONDITIONS OF TRANSPORT AIRPLANES IN ROUTINE OPERATIONS

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NATIONAL ADVISORY COMMITTEE
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SOME MEASUREMENTS OF LANDING CONTACT CONDITIONS OF TRANSPORT AIRPLANES IN ROUTINE OPERATIONS

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SUMMARY

Measurements have been obtained by means of a specially built motion-picture camera of 126 landings of present-day transport airplanes during routine operations at the Washington National Airport in clear-air daylight conditions. From these measurements, sinking speeds, roll attitude angles, and rolling velocities have been evaluated and a brief statistical analysis of the results has been made.

The analysis indicates that sinking speeds of between $3\frac{1}{3}$ and 4 ft/sec will be equalled or exceeded once in 1,000 landings. For the same number of landings, rolling velocities equalling or exceeding 4 to $4\frac{1}{2}$ deg/sec and roll attitude angles equalling or exceeding 6° to $6\frac{1}{2}^{\circ}$ may be expected to occur once.

The equipment and technique employed for these measurements have been found to be accurate and practical, at least for daytime operations. Continued operation of the project, in which horizontal velocities will also be determined, is expected to yield information on the influences of various factors such as airplane characteristics, landing technique, and weather conditions.

INTRODUCTION

One aspect of the problem of rationalizing the requirements and procedures of design for landing loads is that of determining the severity of the landing approach conditions likely to be encountered by an airplane, that is, the magnitudes of sinking speeds, horizontal speeds, attitude angles, angular velocities, lift-weight ratios, and so forth, which may exist at the instant of touchdown and the degree of

correlation between these quantities. For the case of aircraft-carrier operations, a substantial amount of statistical information on landing approach conditions has been obtained by the Navy and is being continually augmented. For land-based operations, on the other hand, very little suitable information is available, particularly for modern transport operations.

The National Advisory Committee for Aeronautics has recently undertaken the project of measuring landing contact conditions of present-day transport airplanes during routine operations. The equipment was set up at the Washington National Airport about the middle of January 1953 with the permission and cooperation of the airport authorities. The results from the first 20 hours of operation of this equipment have been evaluated and are presented herein. Since that time, 194 landings were photographed and, of these, 126 were suitable for evaluation. These landings included measurements for 10 airplanes representing most of the main types in present-day service: Douglas DC-3, DC-4, and DC-6, Convair 240 and 340, Martin 202 and 404, and Lockheed Lodestar, Constellation, and Super Constellation. From these measurements, sinking speeds, roll attitude angles, and rolling velocities have been evaluated and a brief statistical analysis of the results has been made. Although these data are of limited scope, it is believed desirable to make them available as quickly as possible, because of the scarcity of such information.

APPARATUS AND METHOD

A photograph of the equipment used for obtaining information on the landing contact conditions is shown in figure 1. This equipment consists essentially of a constant-speed motion-picture camera fitted with a telescopic lens of 40-inch focal length, supported on a vertical shaft which provides for tracking the airplane only in azimuth. The trailer in which the equipment is mounted can be raised on jacks to permit very accurate leveling of the camera and provide a rigid support.

A sample frame from a typical landing sequence is shown in figure 2. As can be seen from the figure, the instant of contact can usually be determined readily by the appearance of smoke from the tire.

The camera is set up 800 to 1,000 feet from the runway. The actual range of the airplane from the camera can be determined from the photographs by measuring the image wheel-rim diameter. The sinking speed for each of the two wheels of the main landing gear is determined from a consideration of the range and the time rate of change of wheel location, which is obtained by measuring the change in image wheel position over a 5-frame interval (4 time intervals) immediately prior to first-wheel contact. The camera runs at an accurately controlled rate of

25 frames per second; thus, the sinking speed is determined over a time interval of 4/25 second prior to contact, which corresponds to a vertical height of about 1/3 foot for an average sinking speed of 2 ft/sec. The average of the sinking speeds for the two main gear wheels is considered to be the sinking speed for the airplane center of gravity.

The rolling velocity of the airplane is determined from a consideration of the known wheel tread and the difference in the values of sinking speeds for the two wheels. The roll attitude angle at the instant of contact is determined from the relative vertical positions of the wheel images, together with the range and wheel tread. The accuracy in terms of probable error in the quantities determined as a result of errors in film reading, and the error introduced by neglecting the vertical acceleration, is the following: for sinking speed, ± 0.1 ft/sec; for rolling velocity, approximately $\pm 1/4$ deg/sec; and for roll attitude angle, less than $\pm 0.1^{\circ}$. An additional error arises in the determination of the range from measurements of image wheel-rim diameter which results in a probable error of about ± 1 percent of the measurements of sinking speed, rolling velocity, and roll attitude angle. Other sources of error such as those due to refraction, film shrinkage, and timing appear to be negligible. The relative positions of the wheels shown in figure 2 indicate a large roll angle for this landing which is discussed subsequently. (Horizontal speeds can also be determined; however, they have not been evaluated and are not presented herein.) The spot of light appearing in the center of the frame of figure 2 is produced by instrumentation in the camera to denote azimuth angle for use in evaluating horizontal velocity, and is not due to any installation in the airplane. Pilots are unaware that the landings are being monitored.

The number of observations obtained to the present time is too small to permit isolation of various possible influences such as airplane type, airline policy, wind speed and direction, and so forth. The results should be considered as applying to the general class of transport operations under clear-air daytime conditions. Wind velocities ranged from calm up to about 20 mph.

RESULTS AND DISCUSSION

Figure 3 gives histograms of the percentage of the landings occurring in various ranges of sinking speeds. The graph on the left shows the sinking speed of the center of gravity for 126 landings, and that on the right, the sinking speed of the wheel touching down first for 108 landings. The histograms for the two cases are generally similar. The mean value of sinking speed of the center of gravity for the landings observed was 1.3 ft/sec and no landing exceeded a sinking

speed of 3.2 ft/sec. The mean and maximum values of sinking speeds for the first wheel to touch (1.4 and 3.6 ft/sec, respectively) were slightly higher than for the center of gravity.

Figure 4 shows the same results in terms of the probability of exceeding given values of sinking speed. The left-hand plot again refers to the center of gravity, and the right-hand plot, to the first wheel to touch down. The test points define the cumulative frequency distribution, that is, the percentage of landings in which given values of sinking speed were exceeded. Pearson type III curves shown by the solid lines were fitted to the data to provide an indication of the sinking speed likely to be encountered in greater numbers of landings than were actually observed. The dashed curves indicate the region in which the true probability curve can be expected to occur, regardless of the number of observations, with a confidence of 95 percent. The results for the sinking speed of the center of gravity indicate, for example, that 1 percent of the landings, under the conditions of the observations, will equal or exceed 3.0 ft/sec. A sinking speed of 4.0 ft/sec will probably be equaled or exceeded only once in about 4,000 landings. There appears to be no significant difference between the probability to exceed a given sinking speed of the center of gravity and of the wheel to touch first.

Figure 5 presents histograms of the percentage of landings occurring in various ranges of roll attitude angles shown on the left for 100 landings and in various ranges of rolling velocities shown on the right for 101 landings. The mean value of roll attitude angle was 1.1°, and 87 percent of the landings evaluated for roll angle did not exceed 2°. For 99 percent of the landings the roll angle was less than 4°. One landing of the 100 observed was made at a roll angle of $5\frac{1}{2}^{\circ}$ at touchdown. Figure 1 was from this landing. The positive and negative values of rolling velocity refer to rolling in the direction of the wheel touching first and rolling away from the wheel touching first, respectively. As can be seen from the figure, there were almost twice as many occurrences of rolling in the direction of the wheel touching first as there were of rolling away from the wheel to touch first. The mean value of rolling velocities was 0.5 deg/sec and no rolling velocity exceeded 3 deg/sec. The low rolling velocities obtained account for the small differences between sinking speeds of the center of gravity and of the wheel to touch first.

Figure 6 shows the results of roll attitude angle and rolling velocity in terms of the probability of exceeding given values of the roll attitude angle shown on the left and rolling velocity shown on the right. The plotted points again define the cumulative frequency distribution, the solid lines are Pearson type III curves, and the dashed lines indicate the 95-percent confidence band. The graph on the

left indicates that one roll angle in 100 landings would probably equal or exceed 4.3°, and out of 1,000 landings one would probably equal or exceed about 6.2°. The analysis indicated that there was no correlation between roll attitude and sinking speed, nor between rolling velocity and sinking speed. The limitation of roll angle imposed by some part of the airplane other than the landing gear contacting the ground first is from 8° to 16° for four-engine transport airplanes and from 17° to 21° for twin-engine transport airplanes. The results for the rolling velocity indicate that 1 percent of the landings would be expected to equal or exceed 3.3 deg/sec when rolling toward the wheel touching first and about 2.3 deg/sec when rolling away from the wheel touching first. One in 1,000 landings would probably equal or exceed about 4.2 deg/sec or 3.3 deg/sec when rolling toward or away from the wheel touching first, respectively.

CONCLUDING REMARKS

An analysis of the results obtained to the present time on the landing contact conditions of routine transport operations indicates that sinking speeds of between $3\frac{1}{3}$ and 4 ft/sec will be equalled or exceeded once in 1,000 landings. This applies for the center of gravity of the airplane or the first wheel to touch. For the same number of landings, rolling velocities equalling or exceeding 4 to $4\frac{1}{2}$ deg/sec and roll attitude angles equalling or exceeding 6° to $6\frac{1}{2}^\circ$ may be expected to occur once.

The equipment and technique employed for these measurements have been found to be accurate and practical, at least for daytime operations. Continued operation of the project, in which horizontal velocities will also be determined, is expected to yield information on the influence of various factors such as airplane characteristics, landing technique, and weather conditions.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 28, 1953.

EQUIPMENT FOR MEASURING LANDING APPROACH CONDITIONS

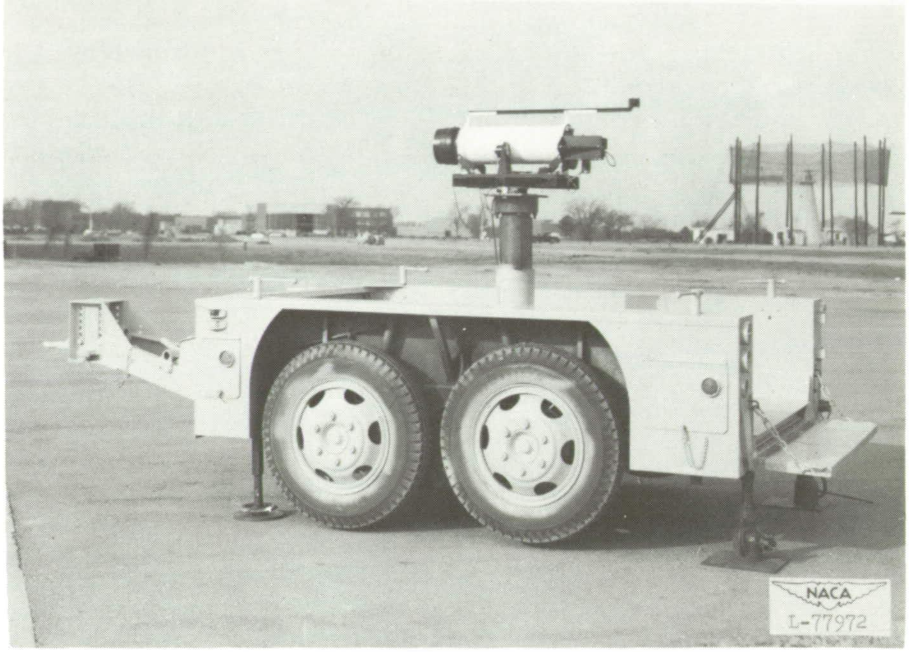

Figure 1.

SAMPLE FRAME FROM A LANDING SEQUENCE SHOWING SMOKE PUFF AT TIRE CONTACT

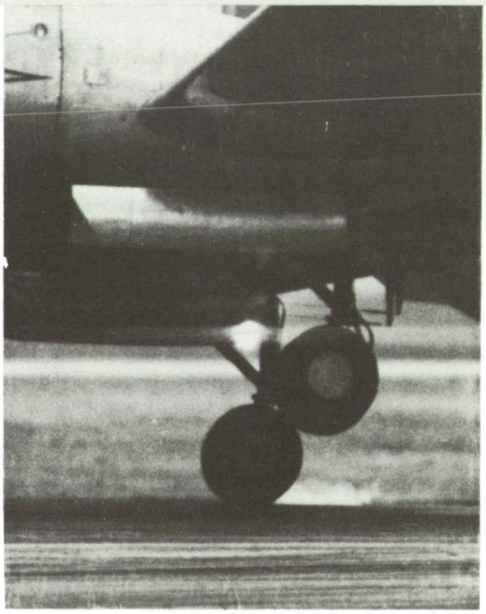

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Figure 2.

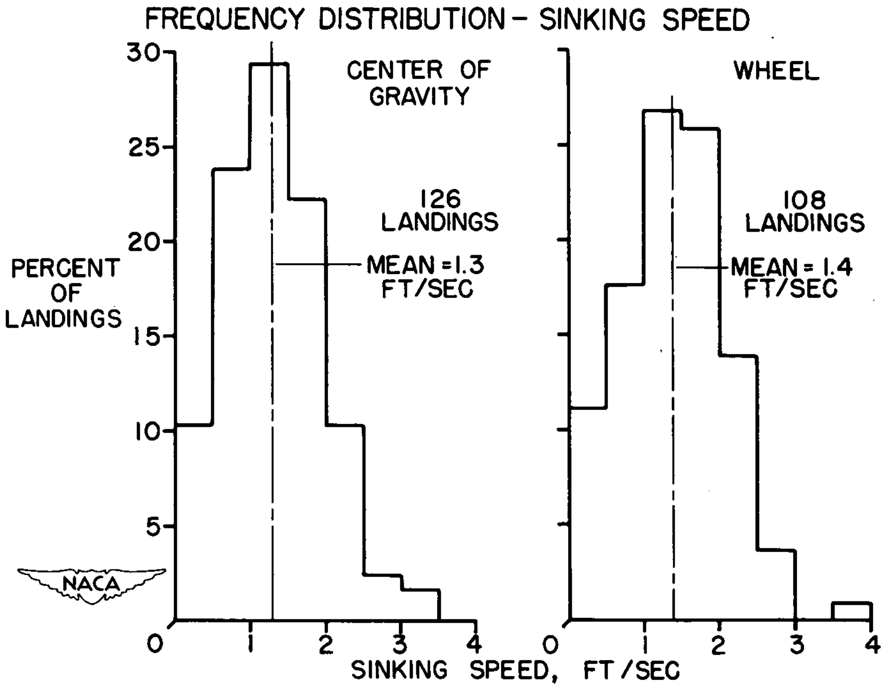

Figure 3.

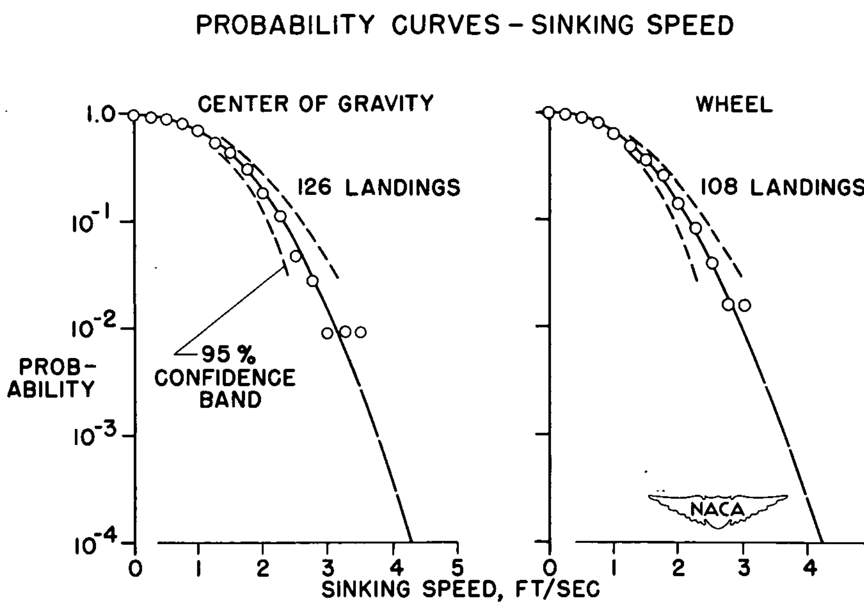

Figure 4.

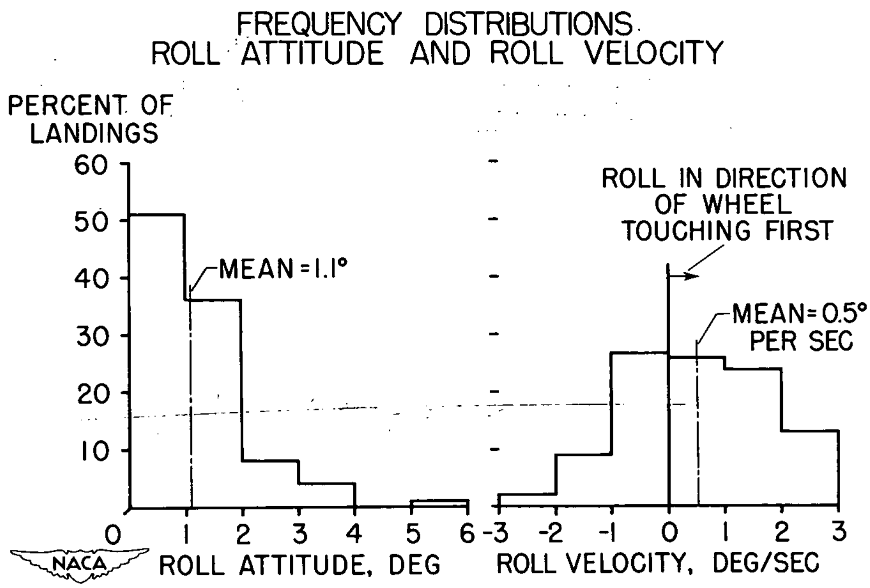

Figure 5.

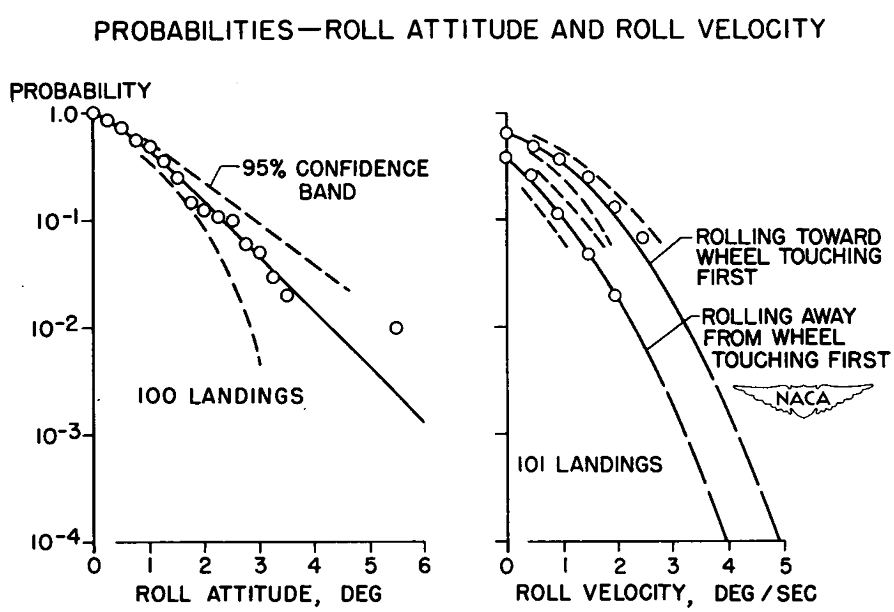

Figure 6.